

INTRODUCTION

In 1992, the Minerals Management Service (MMS) embarked on a project to assess the location and volume of undiscovered oil and gas resources of the United States Outer Continental Shelf (OCS) (i.e., the Federal offshore portion of the United States). This 4-year project was initiated and conducted concurrently with a project to assess the undiscovered oil and gas resources of the onshore and State offshore portions of the United States by the U.S. Geological Survey (USGS) (Gautier and others, 1995; U.S. Geological Survey, 1995). These assessments were conducted cooperatively to develop a comprehensive and up-to-date appraisal of the location and volume of the Nation's undiscovered oil and gas resources as of January 1, 1995.

Some of the results of the MMS assessment are summarized in MMS OCS Report 96-0034 (Minerals Management Service, 1996). The report discusses the history of MMS assessments; summarizes the goals,

commodities, areas, and general methodologies of this assessment; presents the estimates of undiscovered oil and gas resources in each OCS region and the entire OCS from this assessment; and compares these estimates to those from previous assessments.

This report documents the specific commodities, resources, areas, data, and methodologies of this assessment of the Pacific OCS Region and presents the principal results of the assessment of each subarea of the Region. These principal results include descriptions of the petroleum geologic characteristics of each play, assessment area, and province in the Region and the estimates of undiscovered oil and gas resources therein. Additionally, this report presents a summary of the resource estimates, a discussion of the geographic and geologic distribution of the estimated resources, and a comparison of the resource estimates to those from previous assessments.

COMMODITIES ASSESSED

Hydrocarbon resources are naturally occurring liquid, gaseous, or solid compounds of predominantly hydrogen and carbon that exist primarily in the subsurface as crude oil and natural gas. The commodities of hydrocarbon resources that have been assessed for this project are described in the following definitions.

Oil is a liquid hydrocarbon resource, which may consist of crude oil and/or condensate. *Crude oil* exists in a liquid state in the subsurface and at the surface; it may be described on the basis of its API gravity as "light" (i.e., approximately 20 to 50 °API) or "heavy" (i.e., generally less than 20 °API). *Condensate (natural gas liquids)* is a very high-gravity (i.e., generally greater than 50 °API) liquid; it may exist in a dissolved gaseous state in the subsurface but liquefy at the surface. Crude oil with a gravity greater than 10 °API and condensate can be removed from the subsurface with conventional extraction techniques and have been assessed for this project; other oil resources (e.g., crude oil with a gravity less than 10 °API and oil shale) have not been assessed. The volumetric estimates of oil resources from this assessment represent combined volumes of crude oil and condensate and are reported as standard stock tank barrels (hereafter "barrels" or "bbl").

Natural Gas is a gaseous hydrocarbon resource, which may consist of associated and/or nonassociated gas; the terms *natural gas* and *gas* are used interchangeably in this report. *Associated gas* exists in spatial association with crude oil; it may exist in the subsurface as free (undissolved) gas within a "gas cap" or as gas that is dissolved in crude oil ("solution gas"). *Nonassociated gas (dry gas)* does not exist in association with crude oil. Gas resources that can be removed from the subsurface with conventional extraction techniques have been assessed for this project; other gas resources (e.g., gas shale and gas hydrates) have not been assessed. The volumetric estimates of gas resources from this assessment represent aggregate volumes of associated and nonassociated gas and are reported as standard cubic feet (hereafter "cubic feet" or "cf").

Oil-equivalent gas is a volume of gas (associated and/or nonassociated) expressed in terms of its energy equivalence to oil (i.e., 5,620 cubic feet of gas per barrel of oil) and is reported as barrels. The combined volume of oil and oil-equivalent gas resources is referred to as *combined oil-equivalent resources* or *BOE* (barrels of oil equivalent) and is reported as barrels.

RESOURCE CATEGORIES

Hydrocarbon resources are generally categorized by their discovery status and economic viability (fig. 1). Two categories of undiscovered resources have been assessed for this project, and total resource endowments have been estimated. Discovered resources have not been assessed for this project; however, knowledge of their location and volume has been utilized in the assessment of undiscovered resources and estimation of total resource endowments. The following definitions are provided to ensure proper understanding of the assessed resource categories.

DISCOVERED RESOURCES

Discovered resources (reserves) are resources that have been discovered and whose location and volume have been estimated using specific geologic knowledge. They include original recoverable reserves and reserves appreciation.

Original recoverable reserves are the total amount of discovered resources that are estimated to be economically recoverable; they include cumulative production and remaining reserves. *Cumulative production* is the total amount of discovered resources that have been extracted from an area. *Remaining reserves* are discovered resources that remain to be extracted from an area; they include proved reserves and unproved reserves. *Proved reserves* are discovered resources that can be estimated with reasonable certainty to be economically recoverable under current economic conditions. *Unproved reserves* are discovered resources that can not be estimated with reasonable certainty to be economically recoverable under current economic conditions.

Reserves appreciation (reserves growth) is the amount of resources in known accumulations that is expected to augment proved reserves as a consequence of the extension of known pools or fields, discovery of new pools within existing fields, or the application of improved extraction techniques. Prediction of reserves appreciation is generally based on statistical analysis of historical field data. Pacific OCS Region field data are insufficient for this type of statistical analysis; therefore, reserves appreciation in the Region has not been assessed. Appendix A presents a more detailed explanation of the rationale for nonassessment of reserves appreciation in the Region.

UNDISCOVERED RESOURCES

Undiscovered resources are resources that have not been discovered but are estimated to exist outside and within known accumulations based on broad geologic knowledge and theory. Two categories of undiscovered resources—conventionally recoverable resources and economically recoverable resources—have been assessed.

Conventionally recoverable resources are resources that can be removed from the subsurface with conventional extraction techniques (i.e., technology whose usage is considered common practice as of this assessment); they include crude oil with a gravity greater than 10 °API, condensate, and gas but do not include crude oil with a gravity less than 10 °API, oil shale, gas shale, or gas hydrates.

Economically recoverable resources are conventionally recoverable resources that can be extracted profitably under specified economic conditions.

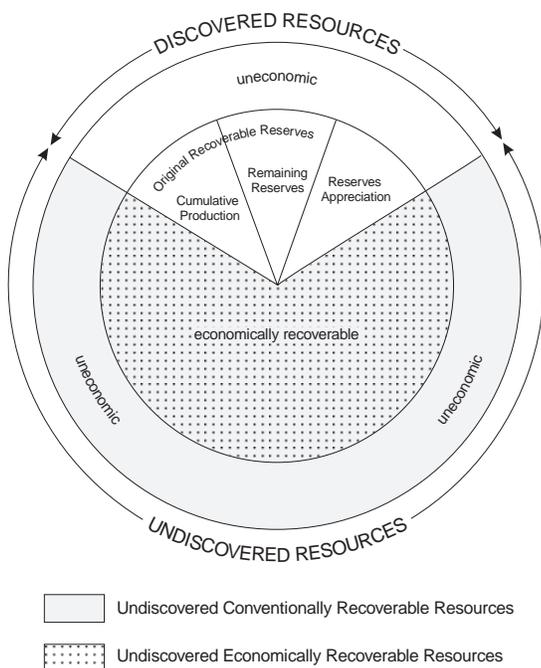


Figure 1. Diagram showing hydrocarbon resource categories discussed in this report. The shaded and stippled areas represent resource categories that have been assessed; the entire circle represents the total resource endowment, which has been estimated. No proportional volumetric scale is implied.

TOTAL RESOURCE ENDOWMENT

The *total resource endowment*—consisting of the sum of the discovered resources (original recoverable reserves) and undiscovered resources—has been estimated for areas where resources have been

discovered. Elsewhere, the amount of undiscovered conventionally recoverable resources composes the total resource endowment. The estimation of total resource endowment is based on previous assessments of discovered resources and this assessment of undiscovered resources.

ASSESSMENT AREAS AND ENTITIES

The Pacific OCS Region is one of four OCS regions of the United States (Minerals Management Service, 1996), and comprises submerged Federal lands offshore Washington, Oregon, and California (see front cover). The geologic framework of the Pacific coastal margin formed the basis for the delineation of assessment areas and the assessment of oil and gas resources in the Region. The following definitions are provided to ensure proper understanding of the assessment areas and entities cited in this report.

PROVINCES, BASINS, AND AREAS

The terms *province*, *basin*, and *area* have the following meanings in this report. A *province* is an area of petroleum geologic homogeneity, which may include one or more geologic basins or geologic areas; the terms *province* and *assessment province* are used interchangeably in this report. A *basin* is a depressed and geographically confined area of the earth's crust in which sediments accumulated and hydrocarbons may have formed; the terms *basin* and *geologic basin* are used interchangeably in this report. A *geologic area* is a depressed and geographically unconfined area of the earth's crust in which sediments accumulated and hydrocarbons may have formed; the terms *geologic area* and *area* are used interchangeably in this report. A *composite assessment area* comprises two or more geologic basins and/or geologic areas that have been combined for the explicit purpose of this assessment.

For this assessment, the Pacific OCS Region was subdivided into six provinces: Pacific Northwest, Central California, Santa Barbara-Ventura Basin, Los Angeles Basin, Inner Borderland, and Outer Borderland (see front cover). The provinces encompass many geologic basins and geologic areas. Detailed descriptions and illustrations of the location, petroleum geology, and resource assessment of the Region and each assessed subarea are provided in the *Petroleum Geology and Resource Estimates* section of this report.

PLAYS

The assessment of undiscovered conventionally recoverable resources within geologic basins and areas was performed at the *play* level. A *play* is a group of geologically related hydrocarbon accumulations that share a common history of hydrocarbon generation, accumulation, and entrapment; the terms *play* and *petroleum geologic play* are used interchangeably in this report.

Plays have been classified according to their exploration and discovery status to qualitatively express the probability that hydrocarbon accumulations exist. *Established plays* are those in which hydrocarbon accumulations have been discovered. *Frontier plays* are those in which hydrocarbon accumulations have not been discovered but in which hydrocarbons have been detected (e.g., shows, bright spots). *Conceptual plays* are those in which hydrocarbons have not been detected but for which data suggest that hydrocarbon accumulations may exist.

Plays have also been classified according to their expected predominant hydrocarbon type. An *oil play* contains predominantly crude oil and associated gas. A *gas play* contains predominantly nonassociated gas and may contain condensate. A *mixed play* contains crude oil, associated gas, and nonassociated gas, and may contain condensate.

Plays have also been classified according to the age and lithology (rock type) of their reservoir rocks. Plays having *Neogene clastic reservoir rocks* include reservoir rocks that consist of Miocene and/or Pliocene sandstone, siltstone, shale, and/or breccia. Plays having *Neogene fractured siliceous reservoir rocks* include reservoir rocks that consist of Miocene fractured chert, siliceous shale, porcelanite, dolomite, and/or limestone. Plays having *Paleogene-Cretaceous clastic reservoir rocks* include reservoir rocks that consist of Cretaceous through Oligocene sandstone, siltstone, and/or shale. Plays having *Melange reservoir rocks* include reservoir rocks that consist of sandstone within Cretaceous through Miocene melange.

For this assessment, fifty individual plays have been defined and described, and 46 of these have

been assessed to estimate the volume of hydrocarbon resources they contain; four plays, which lack sufficient petroleum geologic data or for which data suggest that petroleum potential is negligible, have not been assessed. Detailed descriptions of the location, definition, classification, petroleum geologic characteristics, and resource assessment of each play are provided in the *Petroleum Geology and Resource Estimates* section of this report.

HYDROCARBON ACCUMULATIONS

The terms *prospect*, *pool*, and *field* describe potential and proven hydrocarbon accumulations within

plays and have the following meanings in this report. A *prospect* is an untested geologic feature having the potential for trapping and accumulating hydrocarbons. A *pool* is a discrete accumulation (discovered or undiscovered) of hydrocarbon resources that is hydraulically separated from any other hydrocarbon accumulation; it is typically related to a single stratigraphic interval or structural feature. A *field* is a single- or multiple-pool accumulation of hydrocarbon resources that has been discovered. An *oil field* contains predominantly crude oil and associated gas; a *gas field* contains predominantly nonassociated gas and may contain condensate.

SOURCES OF DATA

The assessment of undiscovered oil and gas resources of the Pacific OCS Region was performed using data and information available to MMS assessors as of January 1, 1995. A large volume and variety of data (including geological, geochemical, geophysical, petroleum engineering, and economic data) were utilized. The specific types, quality, and quantity of data vary among assessment areas and are briefly described in the area-specific parts of the *Petroleum Geology and Resource Estimates* section of this report. A generalized description of the types of data used for the assessment is presented here.

Knowledge of the geologic framework and history of each assessment area was garnered primarily from Federal offshore wells¹ and seismic-reflection profiles². Previous analyses and interpretations of these data by MMS geoscientists were utilized where possible; however, some new and revised analyses and interpretations were performed. Additionally, data from some State offshore and onshore wells, outcrops, and many published sources were considered. Publications that contributed significant information are cited in the area-specific parts of the *Petroleum Geology and Resource*

Estimates section. An appreciable amount of geologic information was also obtained through verbal and written communications with individuals in other government agencies, the petroleum industry, academia, and the local geological community.

The petroleum geologic characteristics (i.e., source rocks, reservoir rocks, and traps) of plays have been predicted using play-specific information from wells and seismic-reflection profiles, and/or analogous information from geologically similar plays along the Pacific coastal margin. Where possible, the presence and generative potential of mature petroleum source rocks have been predicted using geochemical and/or compositional data (some of which were newly acquired); however, the limited amount of these data in most assessment areas commonly necessitated reliance upon analogy. The presence and quality of reservoir rocks, and the thickness of productive intervals, have been similarly predicted using petrologic data from offshore wells and/or by analogy. In many assessment areas, subsurface structure maps generated from the interpretation of seismic-reflection profiles provided the basis for the identification of many potential petroleum traps; the location, areal size, and number of unidentified traps (i.e., those which were not detected with the available data) were subjectively estimated. The petroleum production characteristics (i.e., oil recovery factor, gas recovery factor, and gas-to-oil ratio) of nonproducing plays have been predicted by analogy to geologically similar plays in which production has been established.

Volumetric estimates of discovered oil and gas resources (reserves) in offshore and onshore accumulations were used to develop the predicted probability distributions of pools and fields in some assessment areas. Many of these estimates were

¹ Nearly 1,100 wells (including 327 exploratory oil and gas wells, 765 development wells, and 2 deep stratigraphic test wells) and hundreds of coreholes had been drilled in the Region as of January 1, 1995. Data from many of these wells have been used for this assessment.

² Nearly 200,000 miles of seismic-reflection profiles traverse the Region; the density of the profiles ranges from sparse in frontier areas (e.g., approximately 5 miles between profiles in the central part of the Pacific Northwest province) to extremely dense in mature producing areas (e.g., less than one-half mile between profiles in the Santa Barbara-Ventura Basin province). Interpretations of many of these profiles have been used for this assessment.

obtained from published sources (Sorensen and others, 1993, 1994, 1995; California Division of Oil, Gas, and Geothermal Resources, 1993, 1995; Conservation Committee of California Oil Producers, 1961; Conservation Committee of California Oil and Gas Producers, 1991, 1993) and unpublished sources (Minerals Management Service, 1995). Some estimates were newly developed when these existing sources were considered to be insufficient.

The results of the assessment of undiscovered conventionally recoverable resources (i.e., the

predicted number and volume of undiscovered pools) were utilized in the assessment of undiscovered economically recoverable resources. The economic assessment was predicated on the January 1995 level of petroleum technology, and a number of assumptions regarding future economic conditions (exploration and development costs, oil and gas prices, rates of return), infrastructure requirements (platforms and pipelines), and timing of exploration and development.

PROBABILISTIC NATURE OF RESOURCE ASSESSMENT

There are numerous uncertainties regarding the geologic framework and petroleum geologic characteristics of a given area and the location and volume of its undiscovered oil and gas resources. Some of these include uncertainty regarding the presence and quality of petroleum source rocks, reservoir rocks, and traps; the timing of hydrocarbon generation, migration, and entrapment; and the location, number, and size of accumulations. The value and uncertainty regarding these petroleum geologic factors can be qualitatively expressed (e.g., "there is a high probability that the quality of petroleum source rocks is good"). However, in order to develop volumetric resource estimates, the value and uncertainty regarding some factors must be quantitatively expressed (e.g., "there is a 95-percent probability that reservoir rocks will have porosities of 10 percent or more"). Each of these factors—and the volumetric resource estimate derived from them—is expressed as a range of values with each value having a corresponding probability. The following definitions are provided to ensure proper understanding of the probabilistic nature of this assessment and the resource estimates presented in this report.

Probability (chance) is the predicted likelihood that an event, condition, or entity exists; it is expressed in terms of *success* (the chance of existence) or *risk* (the chance of nonexistence). *Petroleum geologic probability* is the chance that an event (e.g., generation of hydrocarbons), property (permeability of reservoir rocks), or condition (presence of traps) necessary for the accumulation of hydrocarbons exists. A description of the criteria, analysis, and use of petroleum geologic probability in this assessment is provided in the *Methodology* section of this report and in appendix B.

A *probability distribution* is a range of predicted values with corresponding probabilities of occurrence; the terms *probability distribution* and *distribution* are used interchangeably in this report. The estimates of undiscovered conventionally recoverable resources from this assessment have been developed as *cumulative probability distributions*, in which a specified volume or more of resources corresponds to a probability of occurrence. These estimates are reported as a range of values from each cumulative probability distribution, which includes a *low estimate* corresponding to the 95th-percentile value of the distribution (i.e., the probability of existence of the estimated volume or more is 95 in 100), a *mean estimate* corresponding to the statistical average of all values in the distribution, and a *high estimate* corresponding to the 5th-percentile value of the distribution (i.e., the probability of existence of the estimated volume or more is 5 in 100). The low, mean, and high estimates of undiscovered resources that are presented in this report correspond to these specific probabilistic criteria and have not been rounded to reflect their relative precision.

Conditional estimates are estimates of the volume of hydrocarbon resources in an area, given the assumption (condition) that hydrocarbons actually exist; they do not incorporate the probability (risk) that hydrocarbons do not exist. No conditional estimates have been developed for this assessment. *Risked (unconditional) estimates* are estimates of the volume of hydrocarbon resources in an area, including the probability (risk) that hydrocarbons do not actually exist. All estimates presented in this report are risked estimates.